Dispersion of 1,000 Drift Cards Released Over Victoria's Sewage Outfalls

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Introduction

Drift cards, thin buoyant cards imprinted with messages, are useful for measuring the near-surface currents of marine water bodies (Ebbesmeyer and Coomes, 1993). The cards, or in some cases bottles, are released and drift with winds and currents until they beach. Data from recoveries help identify natural collection zones for debris, and help characterize the flushing of inlets or embayments (Ebbesmeyer et al., 1991; Ebbesmeyer et al., 1998a). These data also aid in verifying results from hydrodynamic models (Ebbesmeyer et al., 1991). Results from studies of both active and passive methods of drifter recovery show that drift cards primarily measure near-surface currents, not the variability of human activity along the shore (Ebbesmeyer et al., 1991).

In Puget Sound, Juan de Fuca Strait, and Georgia Strait, scientists have released on the order of 50,000 drifters over the last half-century (Ebbesmeyer and Coomes, 1993; Ebbesmeyer et al., 1995; Ebbesmeyer et al., 1998a; Ebbesmeyer et al., 1998b). Prior to this study, however, only a few satellite-tracked drifters have been released in Victoria Bight (hereafter, the Bight).

Because the city of Victoria, B.C., discharges approximately 85,600 cubic meters (22.6 million gallons) of sewage effluent into the Bight daily (Cokelet, 1995), and because an estimated 10% of the total effluent solids rise to the sea surface in the form of oils and greases (Word et al., 1990), we decided to examine the Bight's near-surface currents. Our primary goal was to use drift cards to infer the fate of the floatable portion of sewage effluent discharged from Victoria's outfalls.

Methods

During the summer of 1997, we released 1,000 drift cards in Victoria Bight, located at the southern end of Vancouver Island, Canada. After consulting engineering drawings supplied by the Capital Regional District (the agency responsible for Victoria's sewage disposal) we chose four release sites: site 1) over the Clover Point outfall; site 2) over the Macaulay Point outfall; site 3) about 400 m east of Albert Head; and site 4) about 650 m northeast of William Head (Figure 1). Sites 1 and 2 were located directly above the diffuser sections of the outfalls, whereas sites 3 and 4 served as statistical control sites.

Using a handheld Magellan Global Positioning System (GPS) unit for positioning, one of us (TJC) released 50 drift cards at each site for a total of 200 cards on five release dates: 19 July; 4 and 17 August; and 6 and 20 September, 1997. Totaled over the five dates, 250 cards were released at each site.

The drift cards were constructed from postcard-sized pieces of thin plywood, painted with non-toxic orange paint. The cards were silk-screened with numbers designating release dates and locations, as well as reporting instructions for beachcombers (including mail and email addresses and a voicemail number).

To analyze the recoveries, we divided the overall region into five recovery zones (Figure 2): 1) San Juan Island vicinity, north of Victoria Bight and eastward into the San Juan Islands; 2) Victoria Bight, from Gonzales Point to William Head; 3) Southwest Vancouver Island, from William Head to Nitinat Inlet; 4) Olympic Peninsula, between Cape Flattery and Dungeness Spit; and 5) Pacific Coast, north and south of Juan de Fuca Strait (Figure 2). With these zones, we performed spatial and temporal analyses of the recoveries, and compared the coastal recovery data with Ocean Surface CURrent Simulations (OSCURS) an empirical, numerical model of daily Pacific Ocean surface currents.

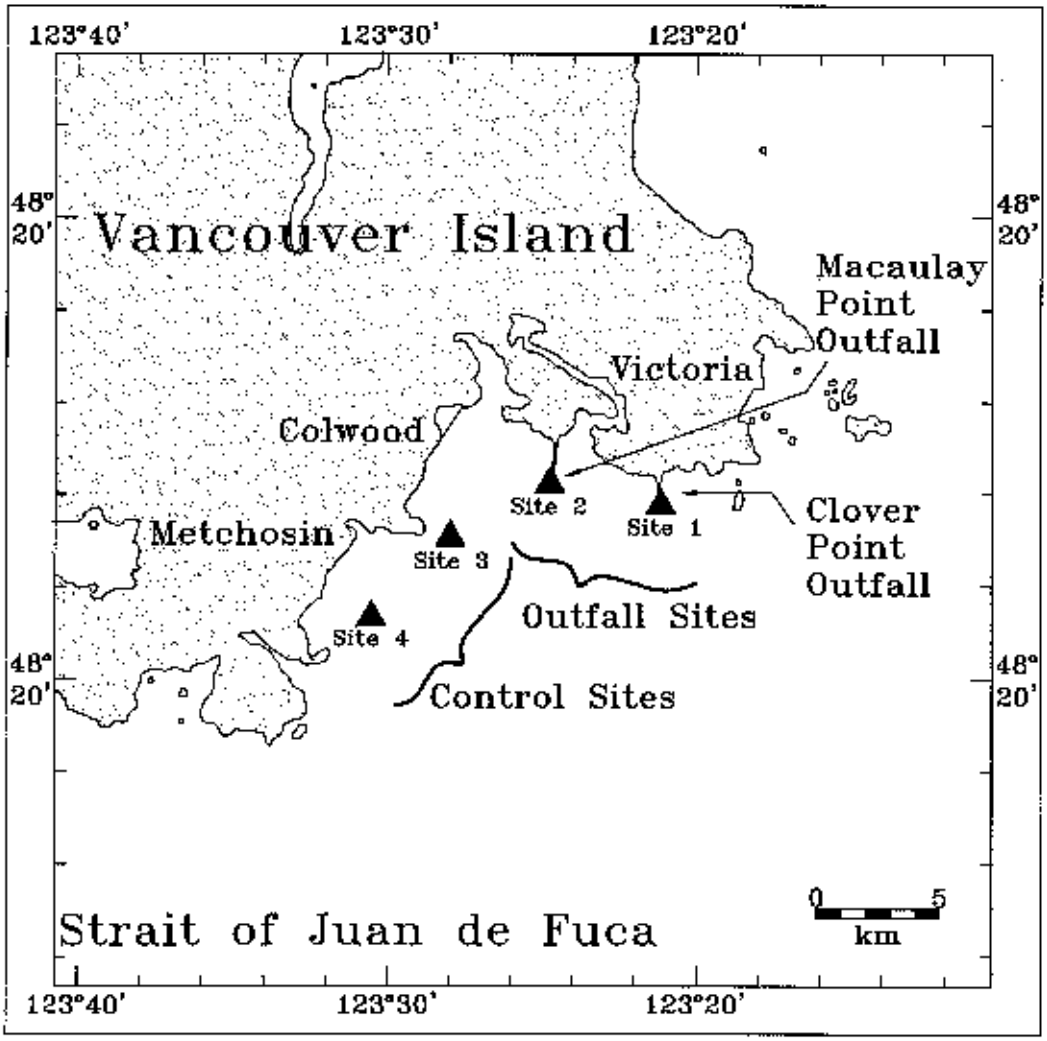

Figure 1. Drift card release sites. Release sites are labeled and marked with solid triangles. The Macaulay Point sewage outfall lies directly under site 2, and the Clover Point outfall lies directly under site 1. Sites 1 and 2 constitute the outfall sites, and sites 3 and 4 are control sites located on the opposite side of Victoria Bight.

For the spatial analysis, used to determine how cards from each site drifted as a whole, we examined recoveries based on release location. Specifically, we tabulated the cards found according to recovery zone for each release site and used these numbers, along with the total number of cards found from each site, to derive the percentage of cards found in each recovery zone for each release site.

For the temporal analysis, used to determine how the cards were affected by wind and Fraser River runoff, we examined recoveries based on release date. Specifically, we tabulated the cards according to recovery zone for each release and used these numbers, along with the total number of cards found from each release, to derive the percentage of cards found in each recovery zone for each release date. We examined only the cards that exited the Bight because we could not disregard the spatial aspects of card release for cards that did not drift far from their origin. In other words, only for cards that drifted substantial distances (and arrived in the same place) was it possible to disregard the relatively small differences in release location. This may be thought of as the inverse of the butterfly effect. Also, the San Juan Island zone was not included in this analysis because too few cards were found there.

We obtained hourly averages of wind speed and direction, gathered at the Race Rocks lighthouse (Figure 2), from the Atmospheric Environment Service of the Canadian Climate Center. With these we computed daily vector averages to examine the wind patterns during the study period. We obtained daily

average Fraser River discharge data for the study period, measured at Hope, British Columbia, from the Water Survey of Canada.

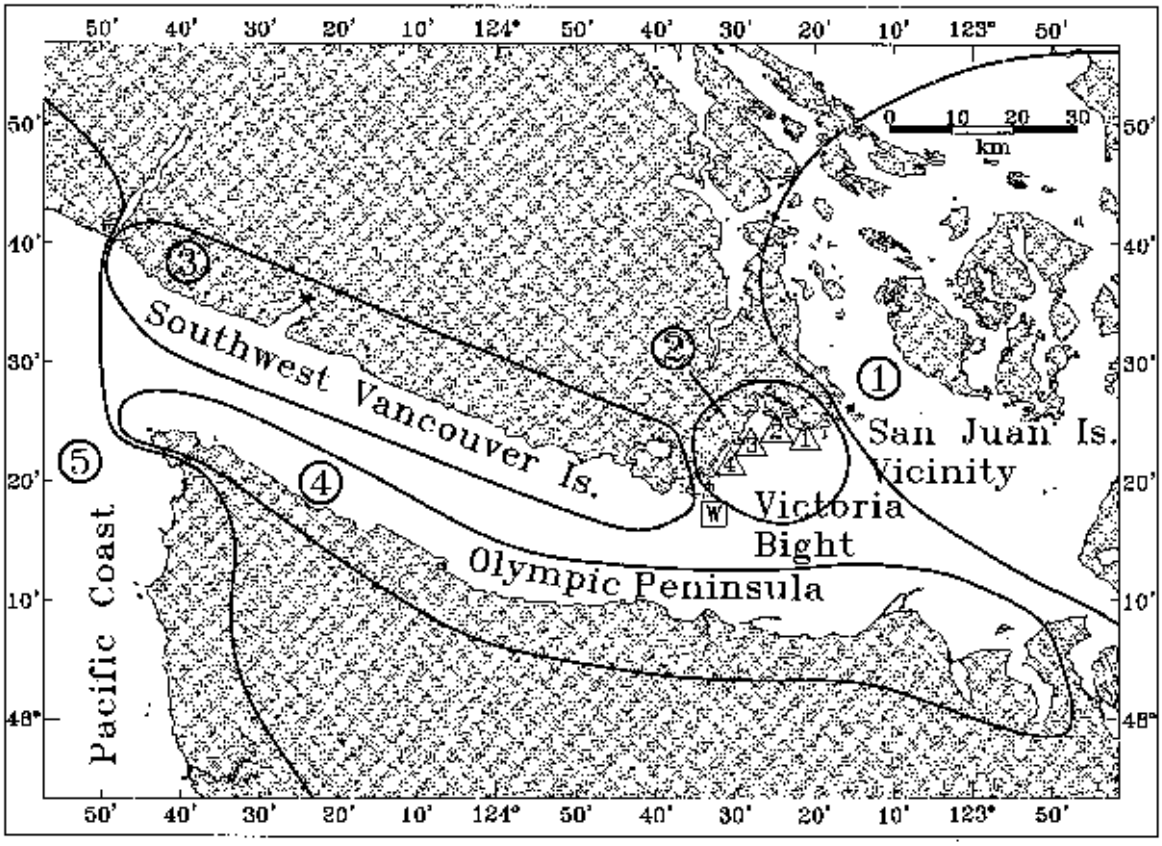

Figure 2. Drift card recovery zones and wind station location. The five recovery zones are labeled and circled. The Victoria Bight zone is comprised of shoreline between William Head and Gonzalez Pt. The San Juan Island vicinity zone incorporates the San Juan Archipelago, Whidbey Island, and Vancouver Island north of Gonzalez Pt. The Olympic Peninsula zone runs from Cape Flattery to Discovery Bay. The Southwest Vancouver Island zone extends from William Head to Nitinat Inlet on the shore of Vancouver Island, and the Pacific Coast zone includes all shoreline outside of the Strait of Juan de Fuca. The Race Rocks wind measurement site is marked with a "W" inside a square.

To examine whether or not drift card recoveries along the Pacific coast reflected dispersal by the prevailing local ocean currents, we used the OSCURS model to track six simulated drifters in the coastal waters of Washington and Vancouver Island OSCURS used empirical formulae, and the ocean-wide gridded daily sea-level pressure data (1946–1998) from the U.S. Navy Fleet Numerical Meteorology and Oceanography Center, to compute the wind-induced component of ocean surface currents in the mixed layer (0–30 m). The daily modeled currents equaled the vector sum of this wind component plus the long-term mean geostrophic current component, computed from long-term mean ocean temperature and salinity fields. OSCURS had been previously calibrated with trajectories of satellite-tracked drifters, and had been found to have a high signal-to-noise ratio (Ingraham, 1997; Ingraham et al., 1998).

Results: Spatial Analysis

The results of the spatial analysis are shown in Table 1. A graph of these percentages versus recovery zone reveals that the drift cards recovered in Victoria Bight were affected by release location more than cards from any other zone (Figure 3). The greatest percentage of cards recovered in the Bight (58.2%) originated from over the outfalls (sites 1 and 2), whereas 31.0% of cards released at site 3, and only 4.7% of cards from site 4, remained in the Bight. Cards found in the southwest Vancouver Island, Olympic

Peninsula, and Pacific coast recovery zones had similar percentages by site, but the percentage for each site varied (most likely) according to the number of cards that escaped Victoria Bight. That is to say, fewer cards from sites 1 and 2 were recovered in these three zones, but fewer cards exited the Bight from these sites.

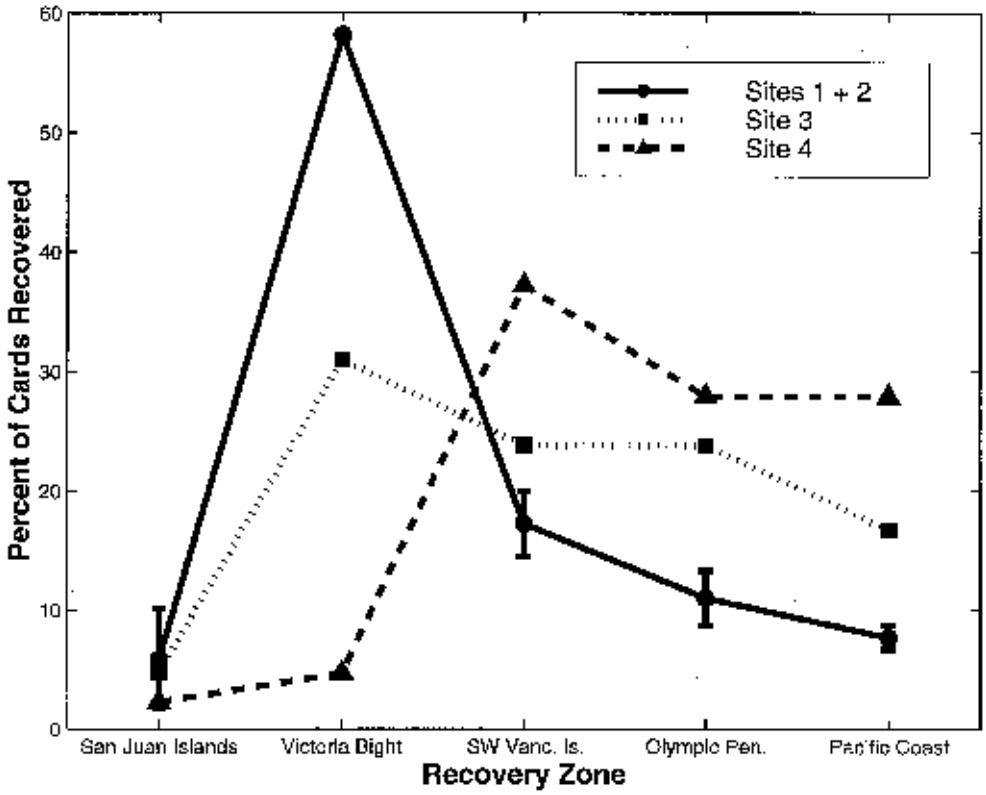

Figure 3. Percentage of drift cards recovered vs. recovery zone. The five recovery zones, from easternmost to westernmost, are listed along the x-axis. Percentages are based on the number of recovered cards from each release site. Data from sites 1 and 2 have been combined and averaged because their values are similar. Error bars have been included to illustrate this similarity.

Table 1. Drift cards released in Victoria Bight analyzed by release site. For each release site, the number of cards released is listed, along with the total percent found, and the percent found within each recovery zone. Numbers given in parentheses denote total number of cards found. We used the total number of cards found from each site to compute the percentages per zone, but used the total number of cards released to compute the total percentage found. For example, of the cards originating at site 1, 40 of the 69 total cards recovered were found in the Victoria Bight zone. Thus, 58.0% of all card recoveries from site 1 were found in the Bight.

			Recovery Zone				
			1	2	3	4	5
Release Site (see Figure 1)	Number Released	Total Found %(#)	San Juan Island Vicinity % (#)	Victoria Bight % (#)	SW Vancouver Is. % (#)	Olympic Peninsula % (#)	Pacific Coast % (#)
Site 1	250	27.6 (69)	10.1 (7)	58.0 (40)	14.5 (10)	8.7 (6)	8.7 (6)
Site 2	250	24.0 (60)	1.7 (1)	58.3 (35)	20.0 (12)	13.3 (8)	6.7 (4)
Site 3	250	16.8 (42)	4.8 (2)	31.0 (13)	23.8 (10)	23.8 (10)	16.7 (7)
Site 4	250	17.2 (43)	2.3 (1)	4.7 (2)	37.2 (16)	27.9 (12)	27.9 (12)

Results: Temporal Analysis

The study bracketed a time period with substantial changes in regional winds and runoff (Figure 4). The wind data reflected the annual transition from summer northerlies to winter southerlies that occurs during fall along the Pacific coast (Ebbesmeyer et al., 1996). At Race Rocks, this transition was from northwesterly sea breezes blowing southeastward through Juan de Fuca Strait in the summer, to variable winds in the fall. The transition occurred between releases 3 (17 August) and 4 (6 September).

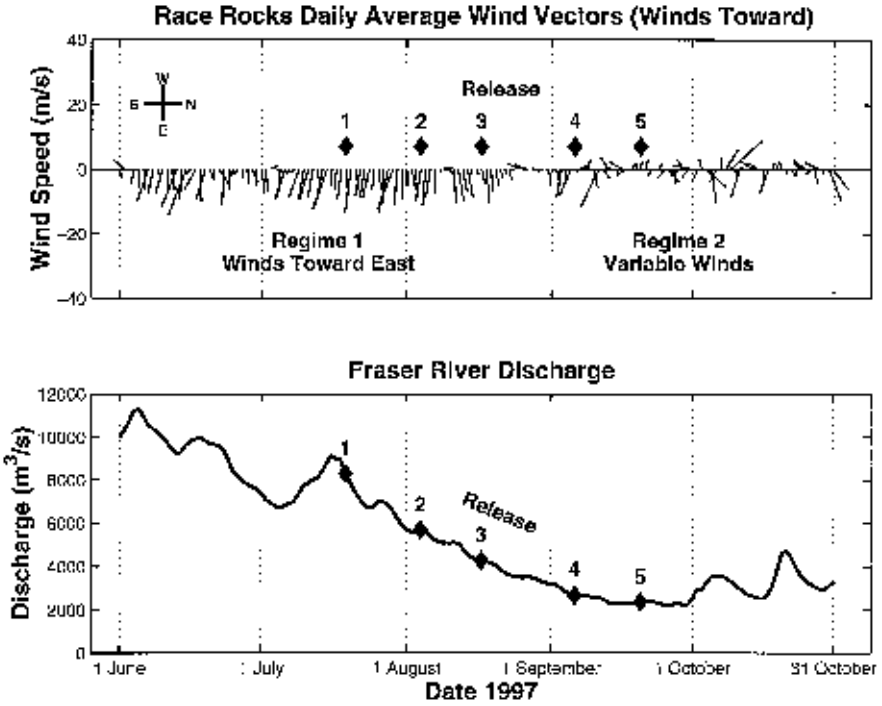

Figure 4. Race Rocks wind vectors and Fraser River discharge. The upper plot shows daily average wind vectors (winds toward) vs. time. For clarity the vectors are oriented with east toward the bottom of the page. Regime 1, northwesterly winds, extends from the beginning of the series through the third week of August. Regime 2, variable winds, begins in late August and extends through the end of the series. The lower plot shows daily average discharge of the Fraser River at Hope, B.C. Releases one through five are marked with a diamond at their respective dates on both plots.

Fraser River discharge also changed dramatically during the study. Daily average flow rates decreased from a June maximum of nearly 12,000 m^3sec^{-1} to ~2,000 m^3sec^{-1} toward the end of September.

The data from Table 2 closely mirrored these changes in winds and runoff (Figure 5). Cards released early in the study were more likely to be flushed to the Pacific coast by the outward flowing current, or be blown to the Olympic Peninsula by the northwesterly winds. As the river input slackened, and the winds became variable, the cards released later in the study tended to collect along the shores of southwestern Vancouver Island.

OSCURS Comparison

Two OSCURS model runs were computed: one during the summer northerly wind regime (17 July to 21 August), and another during the variable wind regime (22 August to 30 September). During the period of northerly winds, the six OSCURS drifters moved steadily southward (Figure 6). During the period of variable winds, simulated drifter movement was variable, with some drifters moving slightly north, and one moving slightly south, but each remaining relatively close to its origin.

Table 2. Drift cards released in Victoria Bight analyzed by release date. For each release date, the number of cards released is listed, along with the total percent of all releases found, and the percent of all recoveries found within each recovery zone. Numbers given in parentheses denote total number of cards found. We used the total number of cards found from each release to compute the percentages per zone, but used the total number of cards released to compute the total percentage found. For example, of the cards released 19 July, 16 of the 54 cards found were found in the Pacific Coast zone. Thus 29.6% of cards from the first release were found on the Pacific coast.

			Recovery Zone		
			3	4	5
Release Date (1997)	Number Released	Total Found %(#)	SW Vancouver Is. %(#)	Olympic Peninsula %(#)	Pacific Coast %(#)
19 July	200	27.0 (54)	9.3 (5)	33.3 (18)	29.6 (16)
4 August	200	24.5 (49)	12.2 (6)	16.3 (8)	18.4 (9)
17 August	200	16.5 (33)	9.1 (3)	18.2 (6)	3.0 (1)
6 September	200	14.5 (29)	48.3 (14)	0.0 (0)	0.0 (0)
20 September	200	24.5 (49)	40.8 (20)	8.2 (4)	6.1 (3)

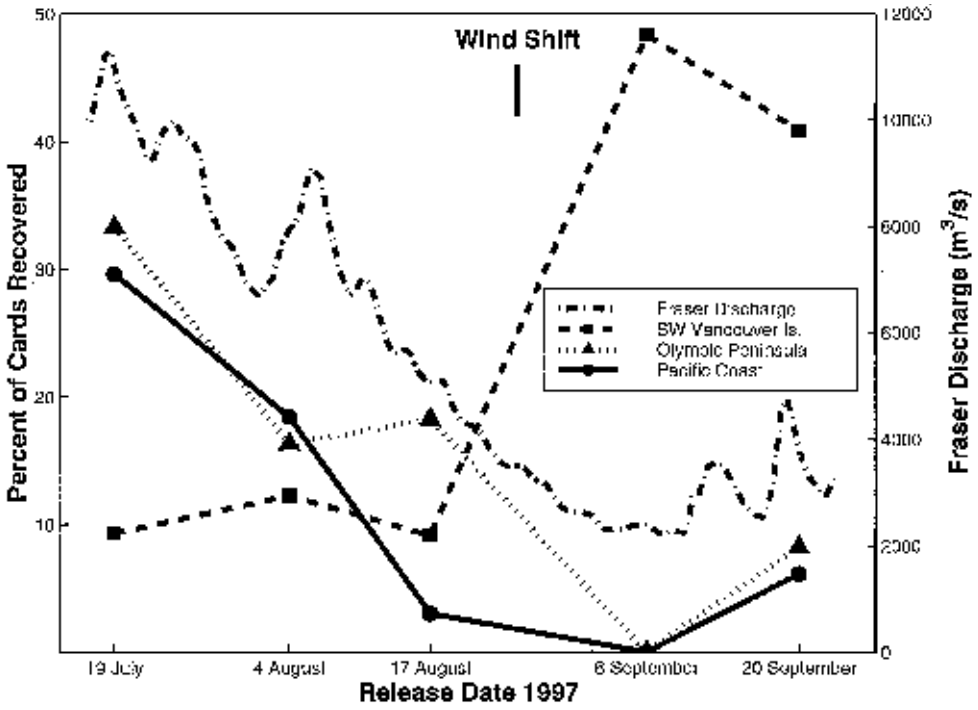

Figure 5. Percent of drift cards recovered vs. release date. The five release dates are listed along the x-axis. The three lines with data markers (squares, circles, and triangles) denote cards recovered in the three analyzed zones. Percentages are based on the number of recovered cards from each release date. Also shown on this graph is the Fraser River discharge, along with the approximate time of the wind regime shift that occurred in late August.

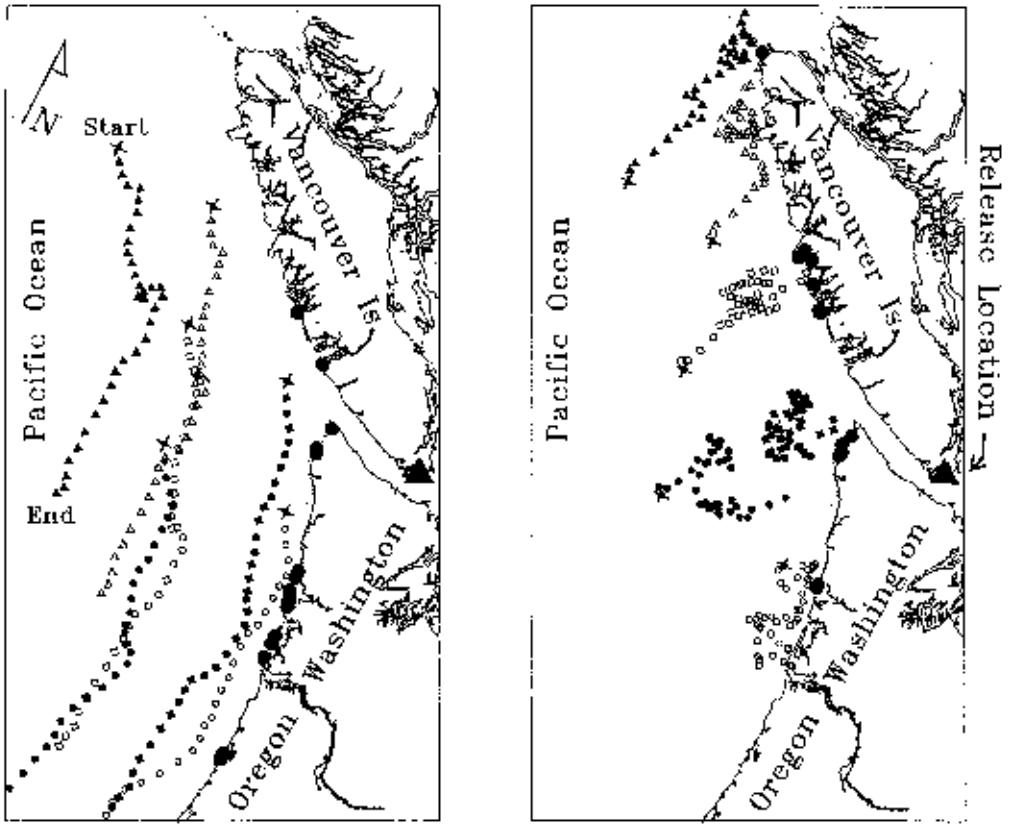

Figure 6. OSCURS model drifter trajectories vs. actual Pacific coast recoveries. Left panel: model drifter trajectories based on atmospheric pressure measurements for 17 July through 21 August, 1997. Also shown are Pacific coast recoveries of drift cards released in July, 1997. Right panel: model trajectories for 22 August through 30 September, 1997. Also shown are recoveries of cards released in August and September. The drift card recoveries in both panels are marked with solid circles along the Pacific coast. The six simulated drifters originated from the points marked by "X." All drift cards originated from the location at the southern tip of Vancouver Island marked by a solid triangle.

The drift cards found on the Pacific coast were distributed in the same pattern. Of the cards released during July, two were found north of the Strait on Vancouver Island, whereas 14 were found south of the Strait on Washington shores. Of the cards released during August and September, seven were found north, and six were found south.

Discussion

During the analysis we sought to answer four questions, the first being, "Did cards released at different sites end up in different locations?" When considering whether or not cards will leave the Bight, the answer is yes. Cards released over the outfalls had almost twice the likelihood of being found in Victoria Bight as cards released at site 3. Compared to cards from site 4, cards from sites 1 and 2 had about 12 times the likelihood of being found in the Bight. However, differences in recoveries for other zones appeared to be related to the differing number of cards that escaped the Bight from each site. Thus, we believe discharge location greatly affected the short-term fate of drift cards in Victoria Bight.

The second question, "Did cards released at different times end up in different locations?" could only be applied to three of the five recovery zones. Release location must be considered when dealing with the Victoria Bight zone, thus complicating this question beyond the scope of our study. The San Juan Island zone could not be analyzed due to lack of data. For the other zones—southwest Vancouver Island, Olympic Peninsula, and Pacific coast—the answer is yes. Differences in wind and river discharge appeared to affect the long-range fate of drift cards.

The third question, "How do these data compare to predicted data?" was addressed with the OSCURS model of Pacific Ocean currents. When compared to Pacific coast drift card recoveries, OSCURS increased our confidence in the drift card data. Cards subjected to summer conditions were recovered predominantly in the south, as predicted by OSCURS. OSCURS predicted variable currents in the fall, during which time card recoveries were distributed evenly north and south. The OSCURS-simulated drifters confirmed that drift card recoveries correlate with coastal surface currents.

Finally, we returned to our initial question, "Where does floatable sewage from Victoria's outfalls go?" The data suggest that roughly 60% is trapped in the Bight, probably due to nearby tidal eddies (Ebbesmeyer et al., 1991). The remaining 40% is dispersed widely, mainly along the Pacific coast, and on both sides of Juan de Fuca Strait. Furthermore, the data suggest that if the outfalls were located in the vicinity of sites 3 and 4, off Albert Head and William Head, flushing of floatable sewage from Victoria Bight may be significantly improved. This not being the case, the ultimate fate and concentration of the floatable sewage trapped in Victoria Bight should be the subject of further research.

Acknowledgements

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